REPORT EM-17

# THE CHLORIDE ION CONTENT OF CONCRETE AGGREGATES FROM SOUTHERN ONTARIO

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This report is published without prejudice as to the application of the findings.

## SUMMARY

The corrosion of reinforcing steel in concrete is a major cause of the deterioration of concrete bridge decks in Ontario. The concentration of chloride ions in concrete is one of the controlling factors of corrosion. Corrosion will not occur if the chloride content is below the threshold value of about 0.04 percent chloride ion by weight of concrete.

The Amabel and Lockport dolomites which form the cap rocks of the Niagara Escarpment contain unusually large amounts of water-soluble chloride ions (0.041 and 0.026 percent by weight chloride ion respectively). These rocks are a major source of the crushed concrete aggregate used in Southern Ontario. The chloride ion content of these rocks exceeds specifications imposed in Europe for the chloride ion content of aggregates for use in reinforced and prestressed concrete.

An investigation was conducted to find the source of the chloride ions contained in the rocks and to ascertain if the quantity of chloride ion found in the rocks was capable of causing the corrosion of reinforcing steel in concrete.

It was found that the chloride ions had been introduced into the pores of the Amabel and Lockport dolomites by leaching of the overlying Salina Formation which contains beds of halite (NaCl).

In order for chlorides in aggregate to cause corrosion of reinforcing steel there must be movement of chloride ions out of the aggregate into the cement paste and pore solutions in contact with the embedded reinforcing steel. Because of the extremely large pore size of the dolomites, resulting in a low degree of saturation even at high humidities, the transport of significant quantities of chloride ions into the pore solutions is difficult. This being the case, it is considered improbable that chloride ions from the Amabel and Lockport dolomites contribute significantly to the corrosion of reinforcing steel embedded in concrete.

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# THE CHLORIDE ION CONTENT OF CONCRETE AGGREGATES FROM SOUTHERN ONTARIO

## INTRODUCTION

In early 1977 the authors received an oral report that screenings from Quarry X, used for backfilling trenches over gas pipes, was causing corrosion of the pipes. An investigation was conducted to determine if screenings from this quarry were capable of causing corrosion and, if so, why?

The Consumers Gas and Provincial Gas companies, the main gas pipeline operators in Southern Ontario, were contacted. They stated that they were not aware that trench backfill material was causing the corrosion of gas pipelines. In any case, corrosion would be unlikely to take place because the pipes are coated and wrapped to prevent corrosion by either chlorides or sulphides. Subsequently, the quarry operator revealed that the spurious report of corrosion had originated from a pipeline contractor who had wished to discontinue the use of Quarry X screenings and transfer his business to another supplier.

The initial investigation of the possibly corrosive nature of the quarry screenings indicated that the chloride ion concentration in the rock from this quarry was unusually high. Aggregate from this quarry was found to contain about 0.12 percent by weight total chloride ion and 0.04 percent by weight water-soluble chloride ion. These values exceed specification limits imposed in Europe for the chloride ion content of aggregates for use in reinforced and prestressed concrete. In view of the detrimental nature of chloride ions on steel in concrete, it was decided to continue the investigation to discover the nature and source of the chloride ion content of this rock and whether or not it could cause corrosion of steel in concrete.

## FIELD AND LABORATORY INVESTIGATION

### GEOLOGY

Quarry X is operating from the Niagara Escarpment in the Amabel Formation of Silurian age. This is the northern lateral equivalent of the Lockport Formation which forms the cap rock of the escarpment to the east of Dundas. The area of interest of the Amabel Formation lies between Georgetown and Dundas. The rocks of the Amabel Formation are composed of a light grey, medium crystalline, macroporous and fossiliferous biohermal dolomite. The Amabel Formation in this area is underlain by two to three metres of Reynales Formation dolomite. This is, in turn, underlain by the Clinton and Cataract Groups. (See Map, Figure 1)

### LABORATORY TECHNIQUES

Rock samples were prepared by grinding to pass a #100 mesh screen. Five-gram samples were submitted to the Chemicals & Metals Unit for the determination of total and water-soluble chloride ion content. The technique used was that described by Berman (1972). The water-soluble chloride analyses reported in Table 1 (Appendix A) were determined by extracting in cold water for a period of two weeks. This technique was too lengthy for the number of samples which were tested. Thereafter, water-soluble chloride ions were extracted by boiling the rock powders in water for five minutes and allowing to cool. A comparison of water-soluble chloride ion contents determined using the two techniques (Table 1 and Table 3, Appendix A) shows that the methods of extraction used have little influence on the chloride ion contents found in samples from the same quarry.

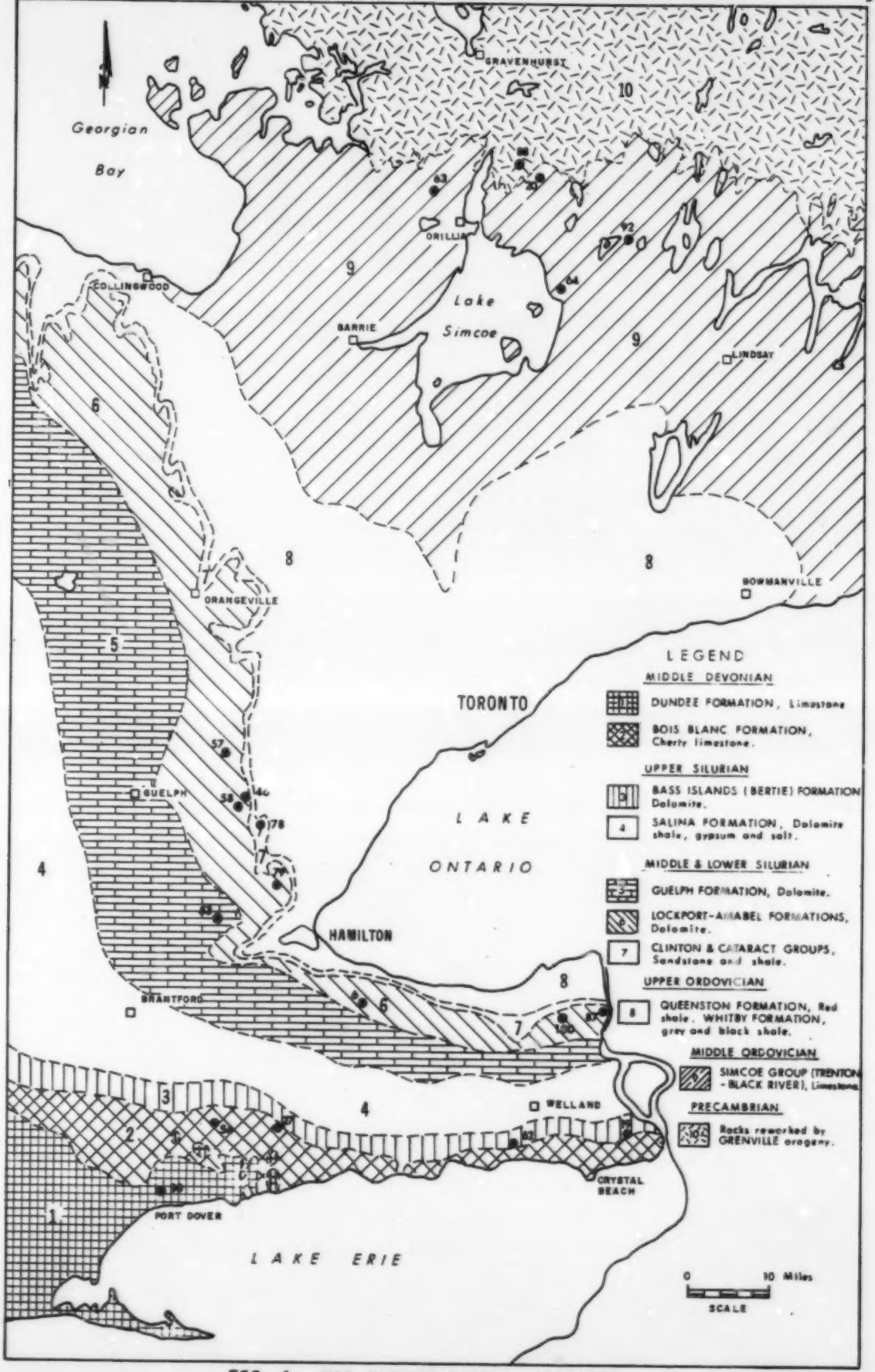


FIG. 1: MAP SHOWING SAMPLE LOCATIONS

## POSSIBLE SOURCES OF CHLORIDE ION FOUND IN QUARRY X

### HUMAN AGENCY

It is the practice of some operators to add sodium chloride to aggregate stockpiles to prevent freezing of the stockpile (Verbeck, 1975). The operator of Quarry X does not follow this practice. Contamination from the application of deicing or dust-control agents to roadways within the quarry may also be discounted due to the small quantities involved. This quarry produces over 1,000,000 tons of aggregate every year. Contamination at the level found (0.12 percent $Cl^-$) would require the addition to the aggregate of over 2,000 tons of sodium chloride every year!

### CONTAMINATION BY GROUNDWATER

If groundwater was causing contamination of the rock from this quarry, it would be expected that a variation in chloride ion content would be found with elevation and porosity. A visit was made to Quarry X in March of 1977. Specimens of rock were collected from various elevations in the west quarry face. The sample locations are show in Figure 2, and the results of chloride ion analysis are presented in Table 1 (Appendix A). It can be seen that there is not a systematic variation in either total or water-soluble chloride ion content with elevation. Samples of water from the quarry were taken and analysed for their major dissolved components. The results are presented in Table 2 (Appendix A). It can be seen that the chloride ion content of the water is an order of magnitude less than the water-soluble chloride ion content of the rocks. The quantity of chloride ion present in the quarry water agrees well with that reported by the Ministry of the Environment (0.0054 percent chloride ion) from two private wells near the quarry. The high chloride ion content of water from the underlying formations is characteristic and is due to the long residence time of water in these rocks.

Groundwater could cause concentration of chloride ions in the Amabel dolomite if evaporative discharge at the surface was taking place. Data is not readily available to construct maps showing

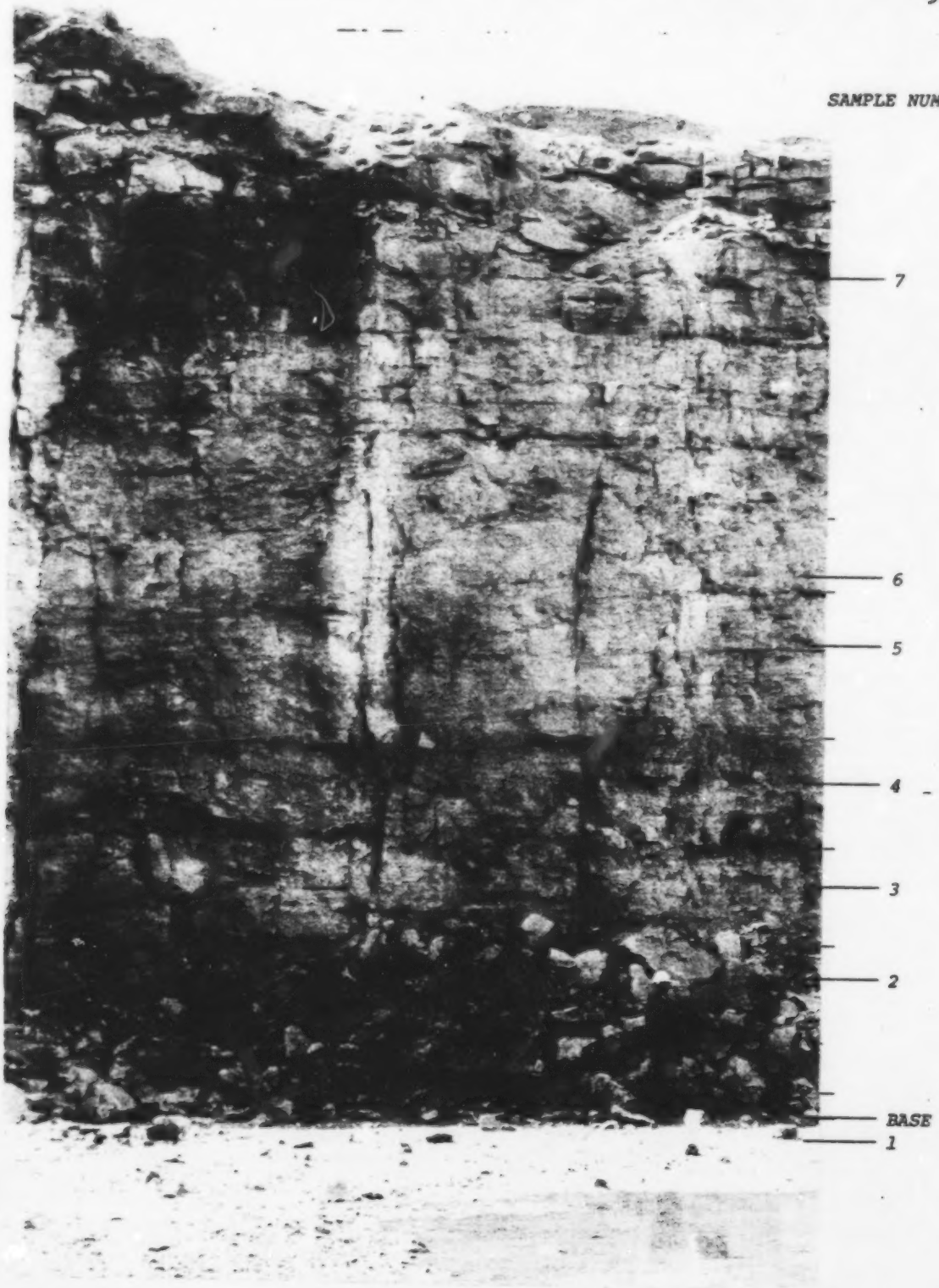


FIG. 2: LOCATION OF SAMPLES FROM QUARRY 'X'

the direction of groundwater flow. Dr. U. Sibul of the Water Resources Branch of the Ministry of the Environment thought it unlikely that evaporative discharge was taking place in the vicinity of the quarry (personal communication). Groundwaters flow down and out at the edge of the Niagara Escarpment as shown by numerous springs along the contact between the Amabel Dolomite and the underlying, less permeable formations.

Petrographic samples of aggregate stockpiles from this quarry had been retained for a number of years. The results of chloride ion analyses of these samples are presented in Table 3. There is no apparent systematic variation with time of either total or water-soluble chloride ion content. Had the chloride ion analyses been caused by contamination from either ground or surface waters, it would have been expected that there would have been rather large variations in the chloride ion content of the aggregate stockpile samples over the years. Both the face samples and the stockpile samples show surprisingly uniform total and water-soluble ion contents.

It is probable that the chloride ion contained in the rocks is contaminating the groundwater rather than the reverse.

## CONTAMINATION BY THE SALINA FORMATION

The results of chloride ion analyses of samples from the main producing quarries in the Amabel Formation are presented in Table 4. It can be seen that the chloride ion contents are uniform despite the fact that the quarries are several miles apart (see Figure 1). The relatively high total water-soluble chloride ion contents of the Amabel dolomite seem to be ubiquitous.

The Guelph-Amabel-Lockport Formations dip gently to the west and are found at a depth of about 300 metres in Southwestern Ontario where they are reservoir rocks for oil and natural gas. These formations are overlain by the Salina Formation, which is composed of: dolomite, shale, gypsum and halite (common rock salt, NaCl). The present outcrop area of the Salina Formation lies several miles to the south and west of the escarpment at the present time (see Map, Figure 1). Grieve (1955) noted that halite crystals occur in rocks

of the Guelph-Amabel-Lockport Formations in Southwestern Ontario. The salt crystals are found filling pores in the dolomite. F. Stoakes (University of Calgary, personal communication) has confirmed the observation of Grieve, noting that pores in the pinnacle reefs of the Guelph Formation are often filled with halite crystals. The salt is believed to have been deposited as a result of leaching of the overlying Salina Formation which contains thick beds of halite (up to 500 metres near Sarnia). Beds of halite are not found in the Salina Formation east of London either because of non-deposition or as a result of leaching by groundwaters. Leaching of the Salina Formation in the past, deposited sodium chloride in the rocks of the Lockport-Amabel Formation which, although not found as discreet salt crystals in the present outcrop area, has nevertheless increased the chloride ion content above that of most carbonate rocks found in Ontario. It is unlikely that rocks above and far below the Salina Formation have been contaminated with sodium chloride. Only those rocks directly below the Salina Formation should contain significant quantities of sodium chloride if the source of the salt was the Salina Formation.

To test this hypothesis, samples taken from many aggregate-producing quarries in Ontario for a previous investigation (Rogers, 1977) were analyzed for their total and water-soluble chloride ion contents. The results are presented in Table 5 and a summary in Table 6 (Appendix A). The quarry locations are shown in Figure 1, and the sample descriptions are in Appendix B. It can be seen that the only quarries producing aggregate with appreciable water-soluble chloride ion contents are those underlying the Salina Formation in the vicinity of the Niagara Escarpment (quarries 6, 46, 53, 57, 58, 78, 79, 87, 100). Aggregates from quarries above the Salina Formation (19, 27, 56, 62, 80) generally show low water-soluble chloride ion contents. The other sample locations (20, 63, 64, 88, 91, 92) are located to the east and north of the escarpment in rocks of the Simcoe Group of Middle Ordovician age. They are sufficiently remote from the Salina Formation so that there has been little opportunity for contamination by sodium chloride.

It was thought that there might be a relationship between the clay content (measured by alumina content) and the chloride ion contents of the rocks. The results of x-ray fluorescence analysis for

$Al_2O_3$ are presented in Table 5 (Appendix A). There is no apparent relationship between the alumina and the chloride contents of the rocks examined. Neither is there a relationship between absorption and the chloride ion content of the rocks.

## COMPARISON WITH OTHER STUDIES

A study conducted by Dr. D.G. Manning in July, 1975, found similar total chloride ion contents of aggregate from Quarry X (about 0.136 percent by weight) to those found in this study. Manning measured the water-soluble chloride ion contents of these aggregates and obtained values of about 0.003 percent by weight. This value is an order of magnitude less than those found in this present study.

Manning took 100 g samples of stone of maximum size of 19.0 mm and immersed them in 100 g of distilled water. The chloride ion content of the water was measured at periods up to 90 days. Manning did not find an increase in chloride ion content with time. No reason for the discrepancy in results obtained in the present study compared with those obtained by Manning was found.

Most of the chemical analysis conducted in this study was done on powdered rock samples. For comparison purposes, an experiment similar to that conducted by Manning was devised. One thousand grams of aggregate of known size was immersed in 1,000 ml of distilled water in a sealed container. After a period of 7 days, the water was filtered off and the chloride ion content of the water determined. The results are presented in Figure 3.

The water-soluble chloride ion contents found in this investigation for the Amabel dolomite (0.041 percent by weight) are of the same order of magnitude as those reported (0.064, 0.035, and 0.062 percent by weight) by Williams and Harris (1970) in carbonate rocks of the Niagara Escarpment from Grimsby and Dundas. It should be noted that Williams and Harris used a different method of extraction of and analysis for chloride ion to that used in this present study.

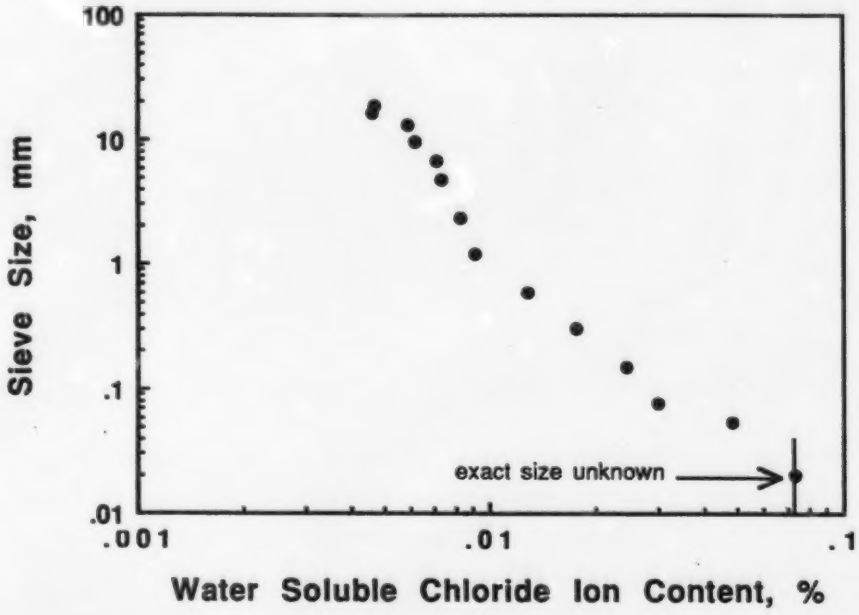
100
10
1
.1
.01
Sieve Size, mm
.001
.01
.1
exact size unknown
Water Soluble Chloride Ion Content, %

FIG. 3

## DISCUSSION

It has been established in the field and laboratory investigation described earlier that the rocks of the Amabel Formation used as sources of concrete aggregate contain remarkably uniform amounts of (0.125 percent) total chloride ion and (0.041 percent) water-soluble chloride ion (see Table 7, Appendix A). The chloride ion is present as a result of leaching of the overlying Salina Formation, which contains large quantities of halite (NaCl). The quarries operating in the Amabel Formation produce a substantial amount of the crushed concrete aggregate used in Southern Ontario.

Are the quantities of chloride present in the aggregate sufficient to initiate corrosion of embedded reinforcing steel in concrete?

### CONTRIBUTION OF CHLORIDE ION TO CONCRETE BY AMABEL DOLOMITE

Concrete normally contains about 50 percent coarse aggregate. Using this figure, it can be calculated that Amabel dolomite will contribute 0.062 ± 0.011 percent total chloride ion and 0.021 ± 0.003 percent water-soluble chloride ion to concrete in which it is used. The fine aggregate, cement, admixtures and mix water will contribute additional quantities of total and water-soluble chloride ion. Dr. Manning reported (personal communication) that Amabel dolomite was responsible for over 75 percent of the background chloride level of a standard mix in which it was used. The contribution of chloride ions by the other components of concrete is, thus, relatively small compared with contribution of the coarse aggregate.

Figure 4 is a plot of total chloride ion content against water-soluble ion content from a concrete bridge containing Amabel dolomite. Dr. Manning, in an unreported study of this bridge, found unusually high chloride contents of samples taken from deep in the structure (up to 25 cm below the surface). These 'background' chloride contents agree well with that expected due to the contribution of chloride by the Amabel dolomite. The results of a chloride ion

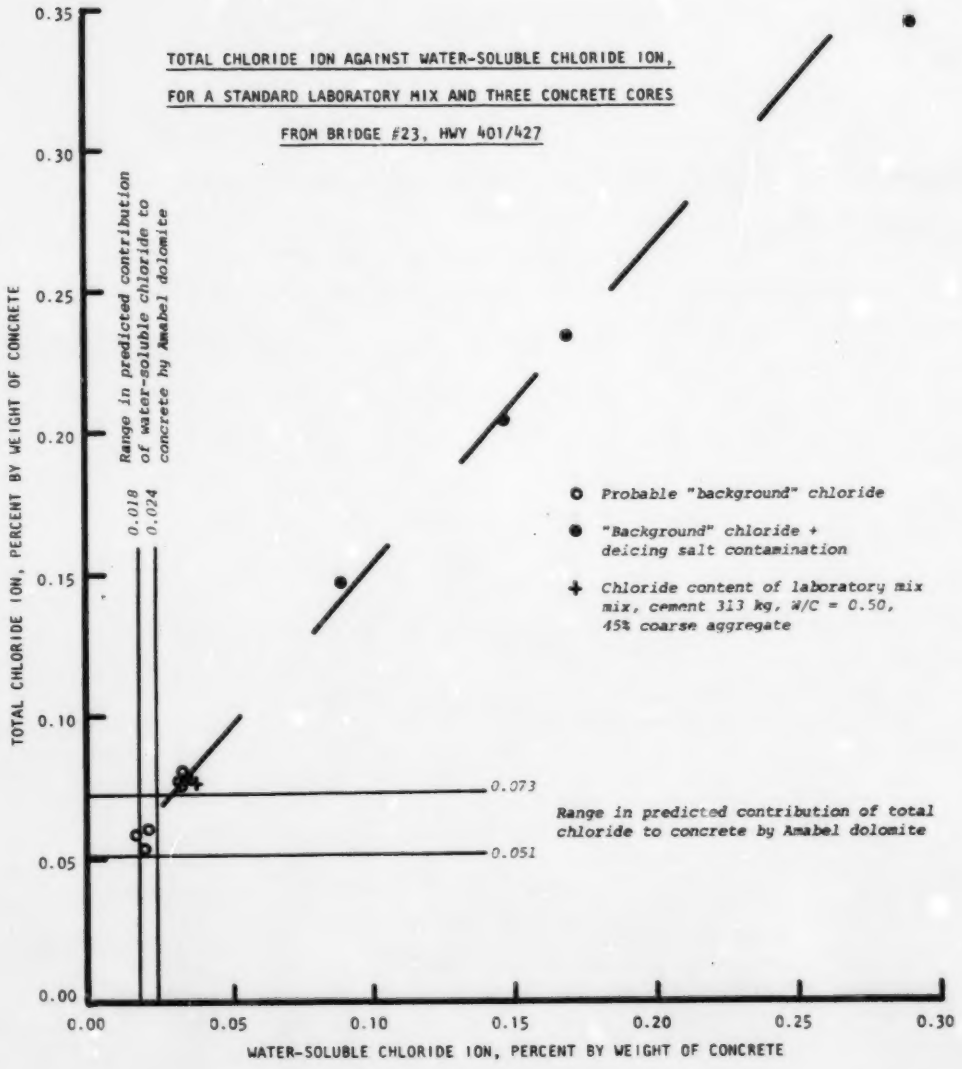
TOTAL CHLORIDE ION AGAINST WATER-SOLUBLE CHLORIDE ION,
FOR A STANDARD LABORATORY MIX AND THREE CONCRETE CORES
FROM BRIDGE #23, HWY 401/427
Range in predicted contribution of water-soluble chloride to concrete by Amabel dolomite
0.018
0.024
Probable "background" chloride
"Background" chloride + deicing salt contamination
Chloride content of laboratory mix mix, cement 313 kg, W/C = 0.50, 45% coarse aggregate
0.073
0.051
Range in predicted contribution of total chloride to concrete by Amabel dolomite
TOTAL CHLORIDE ION, PERCENT BY WEIGHT OF CONCRETE
WATER-SOLUBLE CHLORIDE ION, PERCENT BY WEIGHT OF CONCRETE
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35

FIG. 4

content determination of a laboratory mix containing 45 percent Amabel dolomite is also plotted in Figure 4. The chloride ion content of this sample is larger than that predicted from a knowledge of the chloride ion content of the coarse aggregate, presumably because of the contribution of chloride ions by the other concrete components.

## FOREIGN SPECIFICATIONS & RECOMMENDATIONS FOR CHLORIDE CONTENT

It has been established that aggregate from the Amabel Formation contains about 0.125 percent total chloride ion and 0.041 percent water-soluble chloride ion.

### EUROPE

#### Greater London Council (U.K.)

Specification for Marine Aggregates (1968). Sodium chloride determined using (Volhard titrimetric method) similar to B.S. 812, Part. 4.

- fine aggregate ---- 0.1 percent NaCl
- coarse aggregate -- 0.03 " "

NOTE:

(1) The G.L.C. determines the water-soluble sodium chloride content. The final criteria of acceptance is whether the water-soluble sodium chloride level, expressed as a percentage of the cement content, is greater than 0.32 percent. The allowable sodium chloride concentration level chosen was based on investigations into the use of calcium chloride additives in concrete. They found that in the concretes they examined, no serious corrosion could be detected below about 0.5 percent anhydrous calcium chloride. The figure of 0.32 percent represents a safety factor because of likely variation in sodium chloride levels during mixing and batching. The values for the sodium chloride contents of aggregates were based on the criteria described above and on the sodium chloride levels of material supplied at the time that the specification was written. (G.L.C. Architects Department, Development & Materials Bulletin No. 26, Item No. 6, June 1969).

(2) British Standards Institution amendment to CP 110 and CP 114 requires that calcium chloride shall not be used in concrete involving embedded metal and, further, that: Marine aggregates may not be used in conjunction with prestressed concrete unless they have been previously washed in fresh water to remove the salt (Barfoot, 1976).

The following specifications are from a RILEM Technical Committee Report (1976). It is not known whether or not the specifications refer to total chloride or water-soluble chloride contents. As in other fields, the test method specified is most important. Thus, a direct comparison between these specifications is difficult.

Netherlands

Draft specification NEN3542

Reinforced concrete:

- fine aggregate ---- 0.1 percent $Cl^-$
- coarse aggregate -- 0.05 " "

Prestressed concrete:

- fine aggregate ---- 0.01 percent $Cl^-$
- coarse aggregate -- 0.005 " "

West Germany

DIN 4226.

No specification for reinforced concrete.

Prestressed concrete:

- aggregates -- 0.02 percent $Cl^-$

Austria

ONORM B 3304.

- aggregates -- 0.01 percent $Cl^-$

Amabel dolomite has a water-soluble chloride content in excess of the specification limits applied in Europe for coarse aggregate in reinforced and prestressed concrete.

## UNITED STATES

A literature search failed to reveal any U.S. specifications concerning the chloride ion contents of aggregates. A recent article by Hime and Erlin (1977) noted that while aggregates do not usually contain significant amounts of chlorides, exceptions can occur. They also noted that although chloride ions in aggregate may not be completely available to promote corrosion of reinforcing steel, there had not been a definitive study of this problem.

ACI Committee 201 (1977) made the following suggestions for chloride ion limits in concrete, expressed as percent water-soluble chloride ion by weight of cement:

- prestressed concrete ---------- 0.06 percent
- conventionally reinforced concrete in a moist environment but not exposed to chloride ---------- 0.10 percent
- above ground building construction where the concrete will stay dry (does not include locations where the concrete will be occasionally wetted, such as kitchens, parking garages, and waterfront structures -------- no limit

If the soluble chloride levels are less than these values, the probability of corrosion of reinforcing steel is considered to be low. The test method specified for soluble chloride ion determination is that described by Clear and Harrigan (1977).

A 3,000 p.s.i. concrete with a cement factor of 527 pounds, W/C ratio of 0.50 and containing 45 percent Amabel coarse aggregate, had a calculated (based on aggregate chloride ion content) total chloride ion content of 0.43 percent and a water-soluble chloride ion content of 0.14 percent by weight of cement. The contribution of chloride ion by the other concrete components will increase the chloride ion content of concrete above these values.

It can be seen that the use of Amabel dolomite as aggregate will result in chloride ion contents by weight of cement in excess of those suggested by ACI 201 for reinforced concrete exposed to deicing agents. The ACI Committee report stresses, however, that good judgement should be used in applying the limits suggested.

## CHLORIDE ION CONCENTRATION & CORROSION OF STEEL IN CONCRETE

The mechanism of the corrosion of steel in concrete has been described elsewhere (Verbeck, 1975; Manning and Ryell, 1976). Briefly, there are three essential components necessary for corrosion to take place: oxygen, moisture and chloride ions. The chloride ions increase the conductivity of the electrolyte and also destroy the oxide coating on the steel permitting the release of ferrous ions.

Hausmann (1967) found that the concentration of chloride ions necessary to initiate corrosion depended upon the ratio of chloride to hydroxyl ion activity rather than any fixed amount of chloride ion. When the ratio was greater than 0.6 and free oxygen was present, the corrosion threshold of bare steel rod would be exceeded. The pore solutions of uncracked, uncontaminated concrete have a high pH, largely due to the concentration of calcium hydroxide. Hausmann found that in the presence of free oxygen, a chloride ion content of about 0.070 percent was necessary to cause steel corrosion in saturated calcium hydroxide solutions. Berman (1975), in a similar study, found that corrosion occurred at a solution concentration of sodium chloride as low as 0.03M or 0.107 percent chloride ion. In an empirical study, Stratfull *et al* (1975) found that at the level of the reinforcing steel, 0.59 $k/m^3$ or 0.0255 percent chloride ion in concrete was necessary to cause corrosion. Clear (1974) stated that work in FHWA laboratories had shown that the corrosion threshold of steel was about 0.20 percent chloride ion by weight of cement. For a typical bridge deck, concrete with a cement factor of 700 pounds, this corresponds to 0.035 percent chloride ion by weight of concrete.

Concrete made using coarse aggregate from the Amabel Formation will contain about twice the total chloride ion content of concrete Stratfull *et al* (1975) and Clear (1974) found necessary to cause corrosion (see Figure 4). The figures quoted above tell us that corrosion is possible at these concentrations of chloride. They do not enable us to predict whether or not corrosion will take place.

In summary, it can be said that pore solutions in contact with the steel must contain a certain amount of chloride ion in order for corrosion to occur. The amount of chloride ion necessary to initiate corrosion depends upon the pH of the solution and the availability of oxygen and water. If chloride ions in concrete are

unavailable or not able to go into solution, they cannot cause corrosion. For instance; chloride ion will not be available if it is combined in insoluble cement complexes. Chloride ions in aggregate cannot go into the pore solution in contact with the steel unless there is some transport mechanism between the aggregate and the cement paste. The important factor is not the total chloride ion or even the water-soluble chloride ion content of the concrete or its components, but rather the chloride ion content of the solution in contact with the embedded reinforcing steel.

## MECHANISM OF TRANSPORT OF CHLORIDE IONS

There are two basic mechanisms of transport of dissolved substances in water:

- bodily movement of the solution,
- diffusion of solute ions through the solvent.

In cement paste and aggregate, the operation of the two mechanisms will be governed by the mechanics of moisture transfer through porous bodies.

Pores in porous bodies may be thought of as capillaries. If the water content is low, only the capillaries of the smallest radii will be filled. The small pores are filled with water but the large pores are empty.

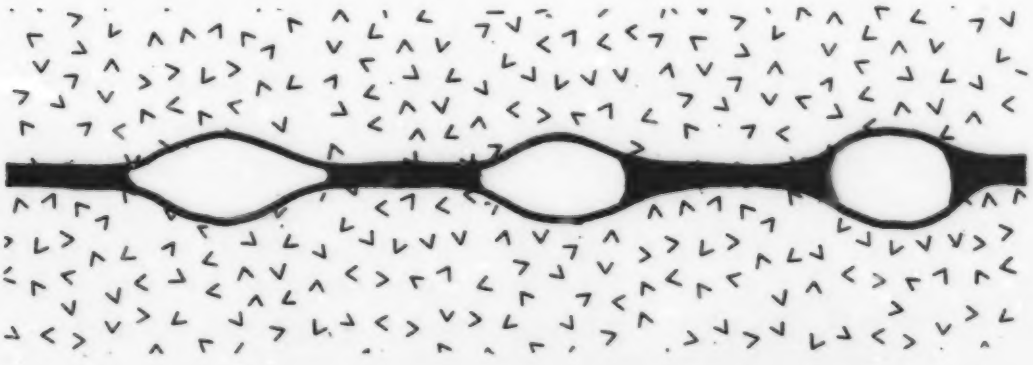

FIG. 5: A PARTIALLY WATER-FILLED CAPILLARY
(from Vos and Tammes, 1969)

Vos and Tammes (1969) showed that moisture flow will occur in the direction of lower vapour pressures in a partially saturated porous body. In Figure 5, a partially filled capillary of variable diameter is shown, such as might be found in any porous body. In order for moisture movement to occur, evaporation must take place at the meniscus at one side of the vapour-air cells and condensation at the other side of cells. There will also be movement of the adsorbed water layer (a few molecules thick) on the surfaces of the large, unfilled capillaries. The movement of moisture in partially saturated porous bodies is a slow process because of the presence of unfilled capillaries forming 'air locks'.

Sodium chloride has a low vapour pressure compared to the vapour pressure of water. The movement of chloride ions will be severely restricted at the minisci of filled capillaries because their low vapour pressure hinders their movement by evaporation through the vapour-air cell.

It can be understood that the transport of dissolved ions in porous bodies depends upon the degree of saturation of the body. In a dry body there can be no movement of either moisture or dissolved ions. As the degree of saturation increases, the amount of capillary filling increases and the number of 'air locks' decreases. Thus, the ease of solvent and solute movement increases as the degree of saturation increases.

The transport of chloride ions from rock aggregates into the surrounding cement paste will be largely controlled by the degree of saturation of the rock. A low degree of saturation will severely restrict the movement of chloride ions out of the rock. A high degree of saturation will allow the movement of chloride ions by bodily movement of solution and by diffusion.

## DEGREE OF SATURATION OF AMABEL DOLOMITE

Capillaries fill with water adsorbed from the air according to the Kelvin equation. The size of the capillary that will fill increases with an increase in the relative humdity of the air. Thus, at 95 percent humidity, all pores of less than 300 Å will be filled with water. It can be understood that, providing the pore-

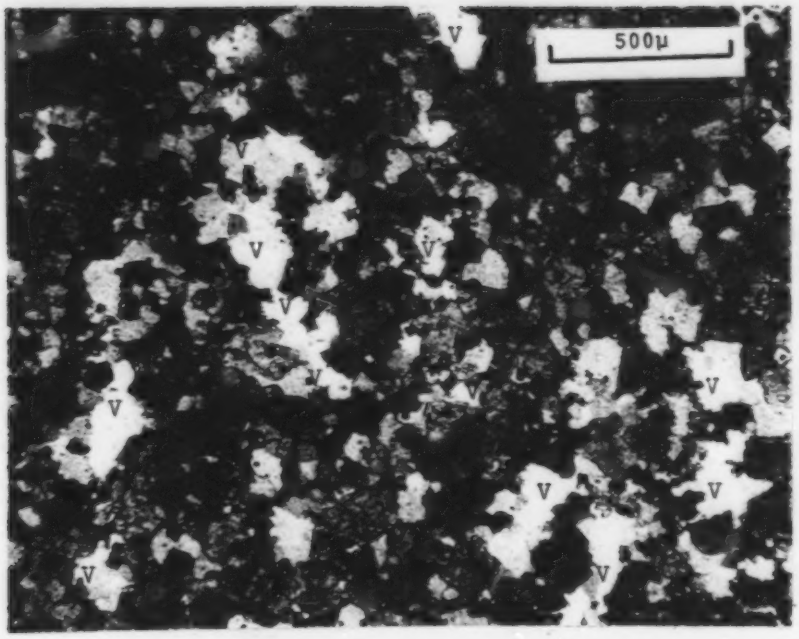


FIG. 6

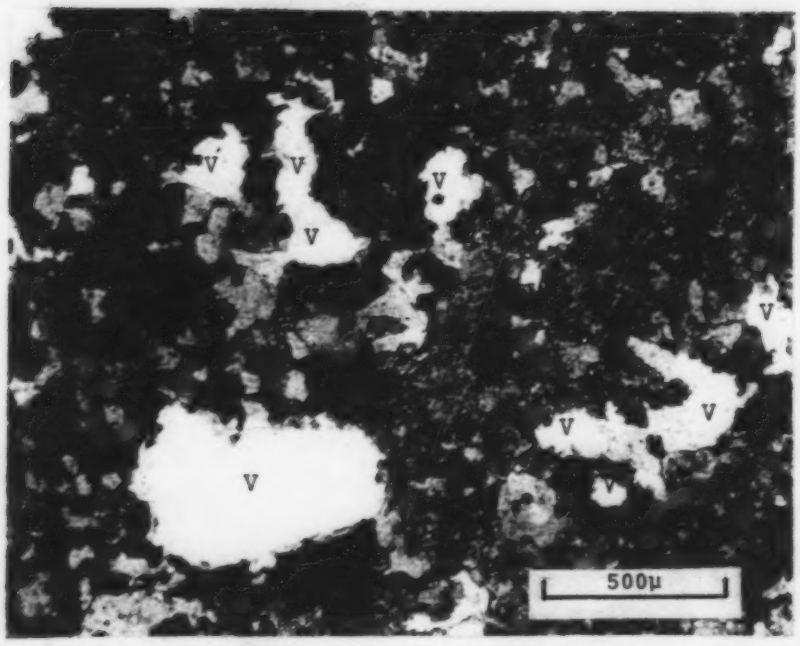


FIG. 7

FIGS. 6 & 7: MICROPHOTOGRAPHS OF TYPICAL AMABEL DOLOMITE
NOTE EXTREMELY LARGE PORE SIZE

(V = voids)

size distribution is suitable, a porous body can achieve a high degree of saturation at high humidities without ever being in contact with a body of water.

Amabel dolomite is a porous (≈ 2 percent absorption) rock. The pores are of very large size (see Figures 6 and 7) and they are, generally, poorly interconnected. The results of adsorption experiments on two of the samples from the Niagara Escarpment are presented in Figure 8. Sample 78.1 is a sample of Amabel dolomite. Sample 6.4 is a very fine-grained, microporous argillaceous dolomite. It can be seen that the Amabel dolomite has a very low degree of saturation, even at the highest humidities. It is safe to say that the only opportunity this rock will get to approach complete saturation in concrete will be when it is permanently submerged in water. In structures above ground, the dolomite pores will remain dry. The very large mean pore size of this rock accounts for the fact that it is an extremely durable stone despite its relatively high water absorption properties compared to other durable aggregates.

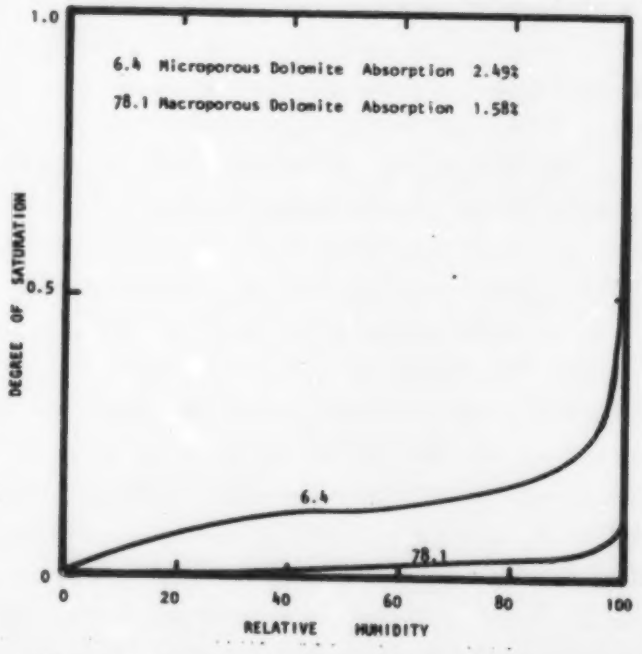


FIG. 8: THE DEGREE OF SATURATION ATTAINED BY TWO DOLOMITES AT VARIOUS HUMIDITIES

(data from Rogers, 1977)

## CONTRIBUTION OF CHLORIDE IONS TO PORE SOLUTIONS BY AMABEL DOLOMITE

It has been shown that the ease with which chloride ions will travel in porous bodies is governed by the degree of saturation of the body. The higher the degree of saturation of the body, the greater the rate at which moisture and dissolved solute may travel through it. It has also been shown that the degree of saturation likely to be attained by Amabel dolomite is extremely low. Thus, the opportunities for the transport of chloride ions contained in the dolomite to regions where they may promote the corrosion of steel are extremely small. The only situation where the dolomite is likely to be completely saturated will be when the concrete in which it is used, is immersed in water for long periods of time. In this case, transport of chloride ions to the cement will take place rapidly due to bodily movement of solution and ionic diffusion. However, corrosion is unlikely to take place because the high degree of saturation of the concrete prevents the access of oxygen, which is another essential element in the corrosion process.

Because of the low degree of saturation normally attained by Amabel dolomite in concrete, the transportation of chloride ions into pore solutions in contact with embedded reinforcing steel is difficult. Aggregate from the Amabel Formation has been used in concrete for more than 25 years. If chloride ions from the aggregates were causing corrosion of reinforcing steel in structures other than highway bridge decks, it is likely that it would have been reported. This partly confirms the conclusion that the chloride ions from the Amabel dolomite are unlikely to contribute significantly to the corrosion of steel.

It is possible that some aggregates may be found that have a high water-soluble chloride ion content and have a pore structure that enables them to attain a relatively high degree of saturation in concrete. Sample 6.4 may be such an aggregate (see Figure 8). In this aggregate, chloride ions will have a greater opportunity for movement than in the Amabel dolomite because of the higher degree of saturation normally attained by this rock.

## CONCLUSIONS

1. The cap rocks of the Niagara Escarpment used as sources of aggregate contain appreciable and possibly deleterious amounts of water-soluble chloride ions. The chloride ions have been introduced to the rocks by leaching of the overlying Salina Formation, which contains beds of halite (NaCl). The Lockport dolomite contains about 0.02 percent water-soluble chloride ions. The Amabel dolomite contains about 0.04 percent water-soluble chloride ions.

2. The Amable and Lockport dolomites contain quantities of water-soluble ions which exceed specification limits imposed in Europe for the chloride ion contents of aggregates for use in reinforced and prestressed concrete.

3. Amabel dolomite used as coarse aggregate in concrete will contribute 0.062 ± 0.011 percent total chloride ions and 0.021 ± 0.003 percent water-soluble chloride ions by weight of concrete. The other components of concrete will contribute additional small amounts of total and water-soluble chloride to concrete.

4. Because of the low degree of saturation normally attained by Amabel dolomite in concrete, the transportation of water-soluble chloride ions into pore solutions in contact with embedded reinforcing steel is difficult. This being the case, it is considered unlikely that chloride ions from the Amabel dolomite contribute significantly to the corrosion of steel.

## RECOMMENDATIONS

1. A limited study should be conducted to confirm the conclusion of this report that the chloride ions in Amabel dolomite are not capable of causing corrosion of embedded reinforcing steel. At that time, consideration should be given to testing a microporous rock of high chloride content to see if this is capable of causing corrosion of steel. Theory indicates that a microporous rock will normally reach a high degree of saturation in concrete and, thus, may allow the transportation of chloride ions to corrosion sites.

2. A limited survey should be conducted to see if reinforcing steel is corroding in structures because of migration of chloride ions from Amabel dolomite to corrosion sites. This survey would require coring of bridges and other structures at depths where chlorides from outside sources (principally deicing agents) had not caused contamination.

3. In view of the conclusions of this report, there is no cause for concern at the present time about the levels of chloride ions found in the aggregate sources examined in this study. While a test and specifications for the chloride ion content of aggregates could be devised, there is no justification for doing so at present.

4. The possiblility should be considered that certain aggregate sources (such as: raised marine beaches) have been contaminated by sea water in recent geologic time. The areas where these sources may be found will be the coast of Hudson Bay, James' Bay and Eastern Ontario. High chloride ion contents are unlikely to be found because of leaching by groundwater since these aggregate sources were deposited.

5. This study has shown that the chloride ion content of fresh concrete may be quite high. In order to determine if

contamination by deicing agents has occurred after some years of service, it is necessary to know the initial or 'background' chloride ion content of the concrete. Consideration should be given to determining the chloride ion content of concrete used in major structures at the time it is placed. This data would be recorded and would serve in the future to enable the detection of chloride ion contamination. The chemical analysis of a few concrete cylinders after compression testing would be adequate for this purpose.

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# APPENDIX A
# EXPERIMENTAL RESULTS

## TABLE 1

### CHLORIDE-ION CONTENT OF FACE SAMPLES COLLECTED FROM QUARRY 'X'

| SAMPLE NUMBER | PERCENT TOTAL CHLORIDE | PERCENT WATER SOLUBLE CHLORIDE | PERCENT 72-HOUR ABSORPTION |
|---|---|---|---|
| 1 | 0.150 | 0.046 | 1.23 |
| 2 | 0.128 | 0.042 | 1.00 |
| 3 | 0.106 | 0.033 | 1.29 |
| 4 | 0.135 | 0.047 | 1.56 |
| 5 | 0.120 | 0.040 | 0.78 |
| 6 | 0.113 | 0.033 | 1.26 |
| 7 | 0.115 | 0.034 | 1.88 |

## TABLE 2

## ANALYSIS OF WATER FROM THE VICINITY OF QUARRY 'X'

| SAMPLE NUMBER | PERCENT BY WEIGHT | | | | | | |
|---|---|---|---|---|---|---|---|
| | $CaO^+$ | $MgO^+$ | $Na^+$ | $Cl^-$ | $SO_3^-$ | $CO_3^-$ | $HCO_3^-$ |
| 1 | .0129 | .0068 | .0028 | .0078 | .0162 | nil | .0177 |
| 2 | .0039 | .0018 | .0009 | .0021 | .0053 | nil | .0061 |
| 3 | .0072 | .0034 | .0025 | .0057 | .0078 | nil | .0122 |
| 4 | .0118 | .0049 | .0110 | .0179 | .0095 | nil | .0273 |
| 5 | .0181 | .0067 | .0064 | .0155 | .0099 | nil | .0348 |

SAMPLE LOCATIONS

1. Pool in quarry floor at base of west face.
2. Water sump in middle of quarry.
3. Water sump near south entrance ramp to quarry.
4. Water tap in workshop washroom (treated water).
5. Water tap in main office washroom (untreated water).

NOTE: The wells supplying the water for Samples 4 and 5 are cased through the Amabel Formation and produce from the underlying formation.

TABLE 3

VARIATION IN CHLORIDE-ION CONTENT OF AGGREGATE

FROM QUARRY 'X' FROM 1972 TO 1976

| YEAR AND SAMPLE NUMBER | PERCENT TOTAL CHLORIDE | PERCENT WATER SOLUBLE CHLORIDE |
|---|---|---|
| 1972-1 | 0.136 | 0.049 |
| 1972-2 | 0.132 | 0.038 |
| 1973-1 | 0.128 | 0.037 |
| 1973-2 | 0.129 | 0.039 |
| 1974-1 | 0.134 | 0.037 |
| 1974-2 | 0.119 | 0.037 |
| 1975-1 | 0.128 | 0.033 |
| 1975-2 | 0.133 | 0.036 |
| 1976-1 | 0.134 | 0.036 |

TABLE 4

CHLORIDE-ION CONTENT OF CONCRETE AGGREGATE FROM

PRODUCING QUARRIES IN THE AMABEL FORMATION

| QUARRY LOCATION NUMBER | PERCENT TOTAL CHLORIDE | PERCENT WATER SOLUBLE CHLORIDE |
|---|---|---|
| 46 | 0.130 | 0.047 |
| 46 | 0.124 | 0.050 |
| 57 | 0.114 | 0.055 |
| 58 | 0.117 | 0.055 |
| 58 | 0.115 | 0.047 |
| 78 | 0.135 | 0.038 |
| 78 | 0.123 | 0.040 |
| 78 | 0.106 | 0.041 |
| 79 | 0.137 | 0.060 |

TABLE 5

CHLORIDE ION CONTENT OF ROCK SAMPLES FROM

AGGREGATE PRODUCING QUARRIES IN SOUTHERN ONTARIO

| QUARRY AND SAMPLE NUMBER | TOTAL CHLORIDE ION CONTENT IN PERCENT | WATER SOLUBLE CHLORIDE ION CONTENT PERCENT | PERCENT ALUMINA CONTENT | PERCENT ABSORBED WATER |
|---|---|---|---|---|
| 6.1 | 0.073 | 0.010 | 3.8 | 2.89 |
| 6.3 | 0.090 | 0.023 | 0.5 | 2.96 |
| 6.4 | 0.069 | 0.015 | 3.3 | 2.49 |
| 19.1 | 0.015 | 0.000 | 1.4 | 1.63 |
| 19.3 | 0.038 | 0.011 | 1.6 | 0.74 |
| 19.5 | 0.021 | 0.000 | 0.3 | 1.84 |
| 20.2 | 0.011 | 0.000 | 0.4 | 0.24 |
| 27.2 | 0.037 | 0.000 | 1.5 | 2.95 |
| 27.5 | 0.021 | 0.007 | 7.3 | 2.69 |
| 27.8 | 0.015 | 0.000 | 0.8 | 2.07 |
| 53.1 | 0.095 | 0.024 | 0.2 | 0.98 |
| 56.3 | 0.038 | 0.006 | 3.2 | 2.08 |
| 56.4 | 0.045 | 0.007 | 0.4 | 1.77 |
| 56.8 | 0.050 | 0.011 | 1.4 | 1.10 |
| 62.1 | 0.047 | 0.000 | 0.6 | 0.92 |
| 62.4 | 0.040 | 0.006 | 0.5 | 1.68 |
| 63.1 | 0.008 | 0.000 | 0.4 | 0.94 |
| 63.4 | 0.009 | 0.000 | 1.5 | 0.84 |
| 63.7 | 0.025 | 0.016 | 0.4 | 0.70 |
| 64.2 | 0.015 | 0.000 | 0.5 | 1.06 |
| 78.1 | 0.109 | 0.037 | 0.3 | 1.58 |
| 80.2 | 0.025 | 0.009 | 0.5 | 0.96 |
| 87.1 | 0.091 | 0.030 | 0.3 | 0.98 |
| 87.2 | 0.400 | 0.007 | 2.8 | 1.71 |
| 87.5 | 0.078 | 0.028 | 0.4 | 2.10 |
| 88.1 | 0.011 | 0.006 | 5.9 | 3.98 |
| 88.2 | 0.014 | 0.000 | 1.4 | 0.92 |
| 88.4 | 0.027 | 0.006 | 0.6 | 1.03 |
| 91.1 | 0.012 | 0.000 | 2.1 | 0.50 |
| 91.2 | 0.018 | 0.000 | 1.0 | 0.72 |
| 92.1 | 0.006 | 0.000 | 0.6 | 0.77 |
| 100.1 | 0.078 | 0.032 | n.d. | n.d. |

TABLE 6

SUMMARY OF WATER-SOLUBLE CHLORIDE ION CONTENTS ON AGGREGATE PRODUCING FORMATIONS IN SOUTHERN ONTARIO

| | NUMBER OF SAMPLES | PERCENT BY WEIGHT $Cl^-$ | |
|---|---|---|---|
| | | AVERAGE | RANGE |
| Rocks overlying the Salina Formation | 12 | 0.0048 | 0.000 - 0.011 |
| Rocks underlying the Salina Formation and forming the cap rock of the Niagara Escarpment | 31 | 0.0381 | 0.015 - 0.055 |
| Rocks underlying the cap rock of the Niagara Escarpment | 13 | 0.0035 | 0.000 - 0.016 |

NOTE: Data from Tables 1, 3, 4 and 5

TABLE 7

SUMMARY OF CHLORIDE ION CONTENT DATA FOR LOCKPORT-AMABEL FORMATION

| FORMATION | TYPE OF CHLORIDE | NUMBER OF SAMPLES | PERCENT MEAN CHLORIDE ION CONTENT | STANDARD DEVIATION |
|---|---|---|---|---|
| Amabel | total | 25 | 0.125 | 0.0109 |
| Amabel | water soluble | 25 | 0.041 | 0.0066 |
| Lockport | total | 5 | 0.080 | 0.0099 |
| Lockport | water soluble | 5 | 0.026 | 0.0068 |

# APPENDIX B
# SAMPLE DESCRIPTIONS AND LOCATIONS

# THE CHLORIDE ION CONTENT OF CONCRETE AGGREGATES IN SOUTHERN ONTARIO

## SAMPLE DESCRIPTIONS AND LOCATIONS

NOTE: The names and locations of the quarries from which samples were taken are listed below with the quarry location number taken from Hewitt and Vos (Limestone Industries of Ontario, Ministry of Natural Resources, 1972). The sample location numbers are the same as those on the map (*FIGURE 1*) of the report.

| SAMPLE NO. & LOCATION NO. | DESCRIPTION |
|---|---|
| 6 | Armstrong Brothers, Vinemount Quarry, Saltfleet Twp. Hamilton-Wentworth R.M. |
| 6.1 | Dolomite, argillaceous, medium brown/grey, aphanitic, medium bedded, microporous, Decew dolomite |
| 6.3 | Dolomite, calcitic, medium grey/light grey, aphanitic, medium bedded, macroporous, chert nodules, Ancaster chert beds of the Goat Island dolomite, Lockport Formation |
| 6.4 | Dolomite, argillaceous, cherty, dark brown/medium grey, medium bedded, laminated, microporous, Goat Island dolomite, Lockport Formation |
| 19 | George Cambell Ridgemount Quarry, Bertie Twp., Niagara R.M. |
| 19.1 | Dolomitic limestone, cherty, medium/light grey, light grey weathering, aphanitic to fine crystalline, thin irregular bedding, glauconitic in part, laminated, fossiliferous, Bois Blanc Formation |
| 19.3 | Dolomite, cherty, medium brown, buff weathering, aphanitic, medium bedded, microporous, Bertie-Akron Formation |
| 19.5 | Dolomite, medium brown/light grey, aphanitic, stylolites, medium bedded, microporous, Bertie-Akron Formation |
| 20 | M. Campbell Quarry, Sebright, Rama Twp., Simcoe Co. |

| SAMPLE NO. & LOCATION NO. | DESCRIPTION |
|---|---|
| 20.2 | Limestone, light grey, lithographic, stylolites, thin to medium bedded, microporous, Gull River Formation |
| 27 | Cayuga Quarries, North Cayuga Twp., Haldimand-Norfolk R.M. |
| 27.2 | Dolomite, mottled light grey/medium grey, aphanitic, medium bedded, microporous, Bertie-Akron Formation |
| 27.5 | Dolomite, argillaceous, medium/dark brown, aphanitic, partly laminated, medium to thin bedded, weathers easily, microporous, Bertie-Akron Formation |
| 27.8 | Limestone, cherty, medium to light grey, medium crystalline to aphanitic, stylolitic, glauconitic, quartz sand, microporous, Bois Blanc Formation |
| 46 | Dufferin Materials & Construction, Milton Quarry, Nassagaweya Twp., Halton Co.<br><br>Amabel Formation |
| 53 | James D. Gray & Son, W. Flamborough Twp., Hamilton-Wentworth R.M. |
| 53.1 | Dolomite, light brown/grey, fine crystalline, macroporous, thin evenly bedded, Guelph Formation |
| 56 | Haldimand Quarries Limited, Hagersville, Walpole Twp., Haldimand-Norfolk R.M. |
| 56.3 | Dolomite, argillaceous, medium brown/grey, microcrystalline laminated, thin bedded, microporous, weathered, Bertie-Akron Formation |
| 56.4 | Dolomite, light grey/brown, aphanitic, laminated, medium bedded, microporous, Bertie-Akron Formation |
| 56.8 | Dolomite, argillaceous, medium brown/grey, dark grey shaley laminations, aphanitic, medium to thin bedded, microporous, Bertie-Akron Formation |
| 57 | Indusmin Limited, Acton Quarry, Esquesing Twp., Halton Co.<br><br>Amabel Formation |
| 58 | Indusmin Limited, Halton Quarry, Nassagaweya Twp., Halton Co.<br><br>Amabel Formation |

| SAMPLE NO. & LOCATION NO. | DESCRIPTION |
|---|---|
| 62 | R. E. Law Crushed Stone Limited, Port Colborne, Wainfleet Twp., Niagara R.M. |
| 62.1 | Dolomite, light brown/grey, aphanitic to microcrystalline, medium bedded, microporous, Bois Blanc Formation |
| 62.4 | Dolomite, medium brown/light brown, aphanitic to microcrystalline, laminated, thick bedded, microporous, Bertie-Akron Formation |
| 63 | Limestone Products Limited, Uhthoff, Orillia Twp., Simcoe Co. |
| 63.1 | Limestone, light brown/grey mottled, medium crystalline to aphanitic, pyrite, microcrystalline, medium bedded, microporous, Gull River Formation |
| 63.7 | Limestone, brown conquinoid calcarenite, thin bedded, fossiliferous, medium crystalline to aphanitic, macroporous, Lower Bobcaygeon Formation |
| 64 | McCarthy Brothers Quarry, Gamebridge, Thorah Twp., Durham Co. |
| 64.2 | Limestone, light/medium grey, brown weathering, medium crystalline, fossiliferous, medium bedded, macroporous, Verulam Formation |
| 78 | Milton Quarries Limited, Milton, Nassawaweya Twp., Halton Co. |
| 78.1 | Dolomite, calcitic, grey/brown, aphanitic to medium crystalline, medium to thick bedded, macroporous, traces brown siderite, Amabel Formation |
| 79 | Nelson Crushed Stone, Nelson Twp., Halton Co. |
| | Amabel Formation |
| 80 | Norfolk Quarry Company, Port Dover, Woodhouse Twp., Haldimand-Norfolk R.M. |
| 80.2 | Limestone, dolomitic, fine crystalline to aphanitic, thick bedded, macroporous, Dundee Formation |
| 87 | Queenston Quarries Limited, Queenston, Stamford Twp., Niagara R.M. |
| 87.1 | Dolomite, calcitic, light grey, medium crystalline, massive bedded, crinoidal, stylolites, macroporous, Gasport Dolomite of Lockport Formation |

| SAMPLE NO. & LOCATION NO. | DESCRIPTION |
|---|---|
| 87.2 | Dolomite, calcitic, argillaceous, medium/dark brown, aphanitic, medium bedded, laminated, microporous, Decew dolomite |
| 87.5 | Dolomite, calcitic, light brown, buff weathering, aphanitic to medium crystalline, porous, macroporous, Goat Island dolomite of Lockport Formation |
| 88 | Rama Township Quarry, Rama Twp., Simcoe Co. |
| 88.1 | Calcareous shaley siltstone, light green, aphanitic to fine crystalline, shale laminations, rapid weathering, soft, microporous, Shadow Lake Formation of the Black River |
| 88.2 | Limestone, argillaceous, light/medium grey, aphanitic, medium to thin bedded, rapid weathering laminated microporous, Gull River Formation of the Black River |
| 88.4 | Limestone, dolomitic, light brown, aphanitic, macroporous, thin to medium bedded, Gull River Formation of the Black River |
| 91 | Roblindale Quarries Limited, Roblindale, Camden East Twp., Lennox and Addington Co. |
| 91.1 | Limestone, argillaceous, dark grey, laminated, medium bedded, microporous, Gull River Formation (upper) of Black River |
| 91.2 | Limestone, medium grey, light grey weathering, aphanitic to medium crystalline, calcarenite, macroporous, Gull River Formation of the Black River Formation |
| 92 | Kirkfield Crushed Stone, Kirkfield, Carden Twp., Victoria Co. |
| 92.1 | Limestone, light/medium grey, aphanitic to medium crystalline, calcarenite, thin to medium bedded, macroporous, Lower Trenton or Upper Bobcaygeon of the Trenton limestone |
| 100 | Walker Brothers Quarry, Thorold, Stanford Twp., Niagara R.M. |
| 100.1 | Sample of HL 6 stone from stockpile, Lockport Formation |